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LIFE HISTORY AND CONTROL OF THE TOMATO PINWORM
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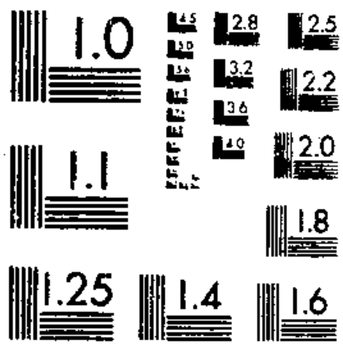

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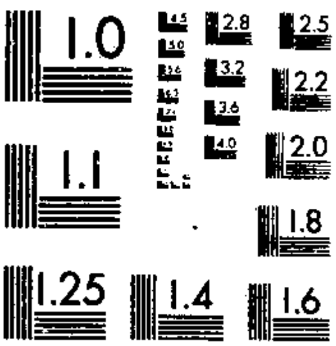

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Life History and Control of the Tomato Pinworm[1]

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SUMMARY

The tomato pinworm (*Keiferia lycopersicella* (Busck))[3] which was first reported in the United States from Imperial County, Calif., in 1923, now occurs in nine States in this country and in Hawaii, Haiti, Mexico, and Peru. Larvae of the pest have been intercepted in tomatoes from the Bahamas and from Cuba.

Heavy losses caused by pinworms attacking tomato fruits have occurred in southern California both to the early- and late-season crops. Since about 1936, however, the losses have been confined principally to the late canning and market crops.

Tomato and potato are the preferred host plants, although actual damage to potato is not common.

The tomato pinworm is a leaf miner and leaf folder which bores into the fruit during the latter half of its larval existence. Leaf injury is not often serious. Damage to each fruit is not great at first but usually causes decay, and the presence of insects or insect injury is objectionable.

The pinworm egg, which is small and light colored, is seldom seen in the field. The larva is ultra ash gray with dark-purple spots. The adult is a small gray moth about one-fourth inch long. The tomato

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[3] Order Lepidoptera, family Gelechiidae.

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pinworm spends the winter or its resting stage as a pupa at or near the surface of the soil. In California development of all stages may continue on tomato plants when temperatures do not reach the freezing point. The moths begin to lay eggs on the leaves of new plants in March and April, and leaf mining and leaf folding follow in succession. This insect is able to develop and increase in numbers entirely on the leaves, but later the fruit is attacked. Development from egg to adult is so rapid that seven or eight generations may occur in one season in California.

The sexes are usually in the ratio of about 45 percent males to 55 percent females. At mean temperatures ranging from 76° to 80° F. the moths lived an average of 7 days when supplied with water only, but 8½ days if given a 10-percent honey solution.

Most of the eggs are laid on the upper half of the tomato plants, and most of them are laid during the first 2 days after the emergence of the moth.

The developmental period varied with the temperature ranging from 26 days at 76° to 80° F. to 100 days at 50° to 55.° Under similar conditions the incubation period ranged from 4 to 30 days and the larval period from 10 to 40 days.

Pupation normally occurs at or near the surface of the soil, 98 percent of the pupae being found within the first inch. Moths cannot emerge normally if buried 2 or more inches in the soil.

The transportation of infested fruit, seedling plants, or picking boxes and the flight of moths are the most important means of dissemination.

Extensive insecticide experiments were conducted in the laboratory and in the field from 1936 to 1941. Many contact insecticides as well as stomach poisons were used. In these experiments the best control was obtained with cryolite. Four applications of cryolite diluted with talc to contain 70 percent of sodium fluoaluminate should be applied at the rate of 20 to 25 pounds per acre at 10-day intervals. Treatment should begin when the first fruit is about an inch in diameter, and the last, or fourth application, should be made just after the first market picking. Young plants in the seedbed or small plants soon after they are transplanted should be dusted if the pinworm is abundant or if heavy pinworm damage is expected.

Cultural practices, such as destroying plant remnants and plowing the fields as soon as the crop is taken off, are important control measures.

INTRODUCTION

The tomato pinworm, a relatively new pest in this country, caused such serious damage to tomatoes in southern California by 1935 that the studies reported in this bulletin were undertaken to determine its biology and to discover a method of control. These studies were continued through 1941.

The larval stage of the insect feeds on the foliage and fruits of tomato and sometimes attacks the foliage of potato and eggplant.

Although the small larva is primarily a leaf miner and leaf folder, it burrows into tomato fruits at the stem end and causes damage characterized by "pinholes." It has therefore become known as the tomato pinworm. Only a small portion of each infested fruit is injured, and unless careful inspection is maintained the presence of the pest in tomatoes intended for processing may be overlooked, resulting in the contamination of the manufactured product.

HISTORY AND DISTRIBUTION

The tomato pinworm was first recognized as a pest of tomato by A. W. Morrill (*14*),[4] who wrote of its occurrence in the Imperial Valley of California and in Mexico as of 1922, stating later, however, in a letter to Keifer (*11*), that 1923 was the correct date. Morrill first sent specimens of the tomato pinworm to Washington from Los Mochis, Sinaloa, Mexico. He noticed that the insects did not attack eggplant and became convinced that they were not the same as the eggplant leaf miner. Nevertheless it was tentatively determined as the eggplant leaf miner (now *Keiferia glochinella* (Zeller)). Since the tomato pinworm was first discovered in the Imperial Valley, it has gradually spread to the north until it has become well established in southern and central California as a serious pest of field-grown tomatoes.

The pinworm has been recorded by Elmore (*6*), Michelbacker and Essig (*12*), the Insect Pest Survey (*20*), and others, from California, Arizona, New Mexico, Missouri, Florida, Mississippi, Virginia, Delaware, and Pennsylvania.

Outside the continental United States, according to the literature, the pinworm occurs in Hawaii, Haiti, Mexico, and Peru, and larvae have been intercepted in tomatoes from the Bahamas, and from Cuba (*21*).

The pinworm causes some damage to field-grown tomatoes in Arizona, New Mexico, and Florida; whereas in Mississippi, Virginia, Delaware, Pennsylvania, and Missouri it has been reported as a pest only in greenhouses and in nearby fields.

A large proportion of the larvae entering the tomato fruit do not penetrate beyond the core, which can be removed when the fruit is canned. Yet infestations have often become heavy enough to make the entire crop unfit for market. Morrill (*14*) (see also *11*) reported 85 percent of the tomatoes infested in a field in the Imperial Valley of California in 1923. Urbahns (*22*) recorded 60 to 70 percent infestation in 1926. Campbell and Elmore (*4*), who reported a 40-percent loss by tomato growers of San Diego County in 1930, reported further (*5*) in 1935 that several fields had been abandoned the previous season because of pinworm damage without the picking of a single fruit. In 1936 a survey was made in 5 counties in southern California in which 16,444 acres of tomatoes were involved. The percentage of fruits infested in different fields ranged from 8 to 99, the average being 34.2 percent.

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[4] Italic numbers in parentheses refer to Literature Cited, p. 29.

Serious injury by the pinworm to tomatoes was reported in the vicinity of Bradenton, Fla., in 1932 by Watson and Thompson (*23*). After the close of the season, all the fruit left on the vines had been attacked.

According to Thomas (*19*), tomatoes grown in greenhouses were seriously damaged in the Kennett Square, Pa., and Wilmington, Del., districts, where the degree of injury was as great as 87 percent in some cases.

Repacking and sorting of the infested tomatoes materially increased the cost of production. In southern California it was necessary to place an inspector at each tomato cannery to inspect each lot of tomatoes from the field. Pinworm injury was the chief cause of cannery rejections in southern California in 1936.

Since 1936 in California there has been a gradual decrease in tomato pinworm abundance, until at present it is largely a late-season pest. This gradual lessening of heavy losses caused by the pinworm has been of great help to the main market and cannery tomato crops, but the late cannery picking and late shipping tomatoes are still subject to heavy losses. Losses are most severe in areas of almost continuous tomato culture, or where outdoor seedbeds are sown before the residue from the previous crop has been destroyed.

HOST PLANTS

Tomato and potato are the preferred host plants of the tomato pinworm. Although serious damage to potatoes is not common, this insect has been taken on potato foliage in widely separated areas. Morrill (*14*) reported in 1925 that potato was an occasional host of this species in Mexico, and Campbell and Elmore (*5*) recorded it on potato in Virginia. In 1936 the foliage of a potato field at Riverside and one at Long Beach, Calif., was strikingly infested by the pinworm.

In the laboratory, pinworm larvae fed readily and developed normally on eggplant (*Solanum melongena* L.) and on the foliage of a native nightshade (*S. umbelliferum* (Esch.)). Larvae of the pinworm placed on the leaves of pepper (*Capsicum* sp.) and on black nightshade (*Solanum nigrum* L.) not only were unable to complete development but most of them also left the plants soon and crawled several feet to tomato plants. The pinworm has not been found on *S. umbelliferum* or *S. nigrum* in the field, although these are commonly growing about tomato plantings in California. Thomas (*19*) reports that eggplant and horsenettle (*S. carolinense* L.) are common host plants in Pennsylvania.

NATURE OF INJURY

The tomato pinworm attacks the leaves of tomato as well as the fruit. The small larvae mine the leaves, feeding only on the inner part and leaving the upper and lower surfaces intact. Later, protective leaf folds are formed from which the larvae continue to feed on the inner parts of the leaf. This type of feeding causes large blotches adjacent to each leaf fold (fig. 1).

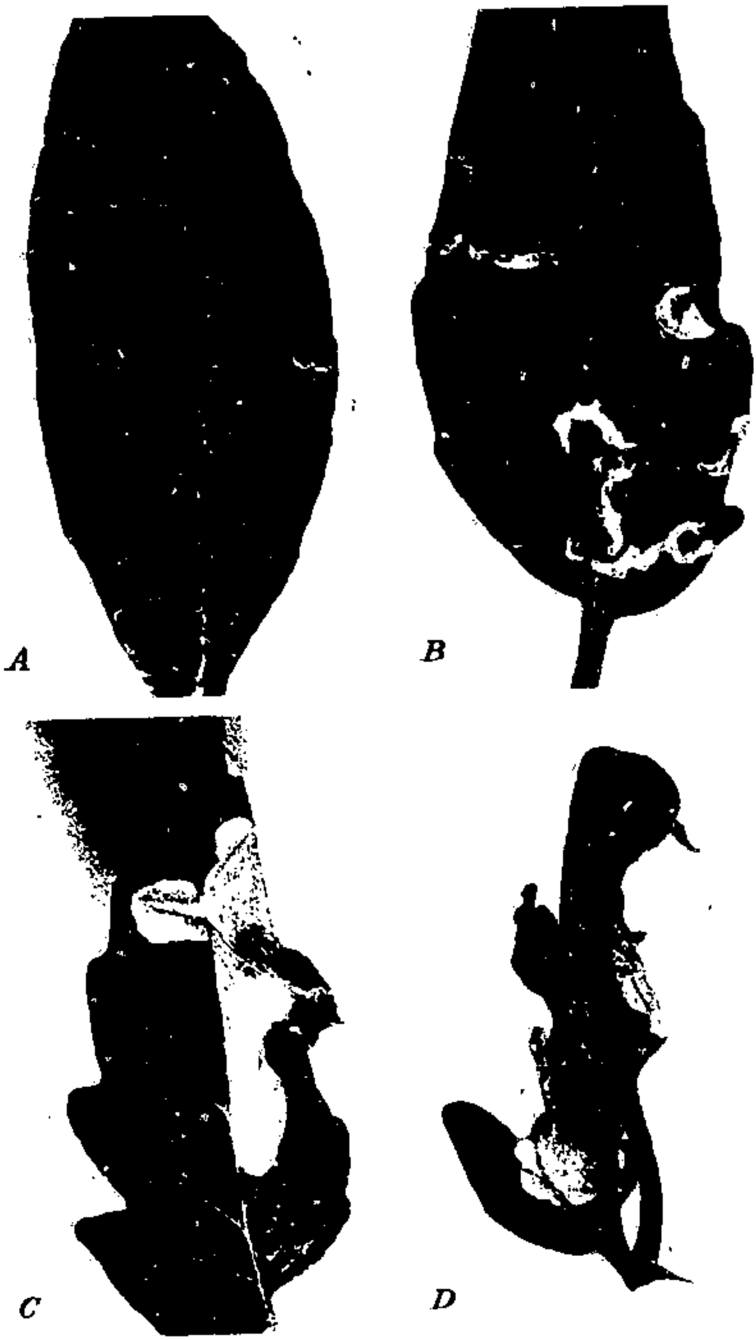

FIGURE 1.—Tomato leaves mined by the tomato pinworm: *A*, Mines made by the very young larvae, ×5; *B*, typical appearance of leaf mine after the larvae are a few days old, × 5; *C*, leaf fold made by a larva, showing typical transparent leaf blotch or mine, × 4½; *D*, pinworm injury to leaves in an advanced stage of development, × 2½.

A large number of leaves may be thus destroyed, but the injury to the plant from this source is not so important as is the damage by the larvae to the fruit (fig. 2).

Larvae that have mined the calyx lobes, and many of those from the leaf mines nearby, enter the fruit instead of folding the leaves. Usually the larvae enter the fruit beneath the calyx lobes or fruit stems (fig. 2, *A* and *B*), but in heavily infested fields about 50 percent of the injured fruit may be damaged in other places as well (fig. 2, *C*).

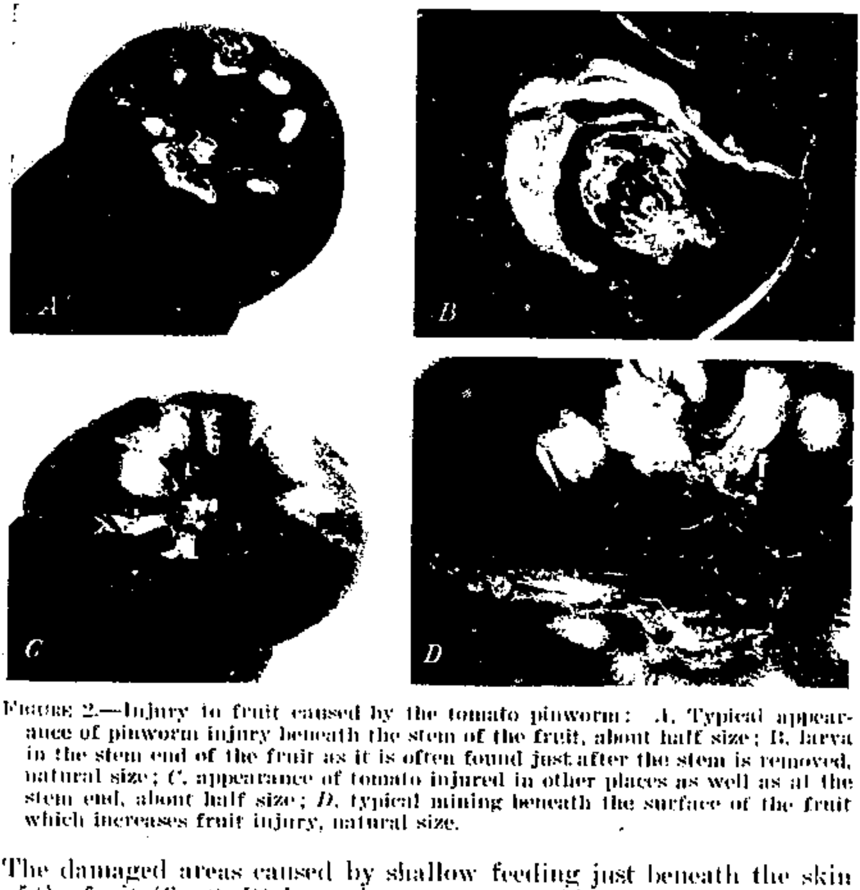

FIGURE 2.—Injury to fruit caused by the tomato pinworm: *A*, Typical appearance of pinworm injury beneath the stem of the fruit, about half size; *B*, larva in the stem end of the fruit as it is often found just after the stem is removed, natural size; *C*, appearance of tomato injured in other places as well as at the stem end, about half size; *D*, typical mining beneath the surface of the fruit which increases fruit injury, natural size.

The damaged areas caused by shallow feeding just beneath the skin of the fruit (fig. 2, *D*) have the appearance of blotches. Larvae that enter the fruit beneath the stem penetrate to a depth ranging from one twenty-fifth to three-fourths of an inch. Many of the larvae in the fruit beneath the stem feed only in the core, which can be removed at the cannery.

SYNONYMY

The tomato pinworm, which was at first mistaken for the eggplant leaf miner (*Phthorimaea glochinella* (Zell.)) (*8*, *13*), was later described as a new species by Busck (*1*), who called it *Phthorimaea lycopersicella*. Busck (*2*) later extended the genus *Gnorimoschema* to include *Phthorimaea* Meyrick, over which it took precedence. In 1939

Busck (*3*) erected a new genus with *Gnorimoschema lycopersicella* (Busck) as the genotype and named it *Keiferia* in honor of H. H. Keifer of the California State Bureau of Entomology and Plant Quarantine.

A species of moth, *Keiferia elmorei* (Keifer), which occurs on native nightshade and is closely related to the tomato pinworm, was at first identified as the tomato pinworm. Later, while preparing figures and the description of *Keiferia lycopersicella*, Keifer (*10*) noticed that the moths before him could really be separated into two distinct types. This led to the description by Keifer of the native nightshade moth as a new species. This clarified the distribution of the tomato pinworm because *Keiferia elmorei* occurs on *Solanum xantii* and *S. umbelliferum* in California as far north as Napa County, whereas the tomato pinworm occurs only on cultivated plants and is more restricted in distribution.

DESCRIPTION OF STAGES

The adult pinworm (fig. 3, *A*) is a small gray moth about a quarter of an inch long; Busck's description of the tomato pinworm is as follows (*1*):

Alar expanse: 9-12 mm. Labial palpi with short furrowed brush on underside of second joint, terminal joint somewhat thickened with scales, compressed with extreme tip pointed, slightly projecting above the scaled part; ochreous white, externally mottled with dark fuscous; terminal joint with a faint ill-defined fuscous annulation before the tip and with extreme apex fuscous. Face and tongue ochreous white. Head and thorax mottled with fuscous. Antennae yellowish fuscous with narrow, dark fuscous annulations. Forewings elongate ovate, apex bluntly pointed, termen oblique; venation typical of the genus, 12 veins, 2-6 separate, equidistant, 7 and 8 stalked to costa; ground color ochreous gray, heavily overlaid and mottled with dark fuscous scaling, and with ill-defined and indistinct, broken longitudinal, ochreous streaks; discal stigmata hardly indicated; plical spot on middle of fold faint and ill-defined, blackish; cilia ochreous gray. Hind-wings with apex pointed, produced; termen deeply sinuated; 8 veins, 3 and 4 connate, 5 approximate, 6 and 7 parallel; light ochreous fuscous; a strong pencil of hair-scales, dilated at tip, from base of costa in the males, reaching to beyond middle of wing, yellowish. Abdomen dark fuscous above with two basal joints slightly lighter, ochreous, underside light ochreous, sprinkled with fuscous. Inner side of legs light ochreous, outer side heavily barred with dark fuscous.

Keifer (*9*) has also given the species an excellent description in which he compares the tomato pinworm with other species of *Keiferia* from California.

The egg of the tomato pinworm is ellipsoid, 0.37 by 0.23 mm. It is light yellow when first deposited but gradually darkens to a light orange before hatching time. As the shade of the egg darkens, the developing embryo likewise assumes a darker color, until just before hatching the dark head capsule and other features of the small larva are visible through the chorion.

Newly hatched larvae average 0.85 mm. in length with an average head-capsule width of 0.55 mm. The head capsule is dark brown and the remainder of the body a yellowish gray common to many newly hatched lepidopterous larvae.

There are four instars. The head capsules of 18 first instars measured 0.14 to 0.157 mm., with a mean of 0.15 mm.; in the second instar 13 head capsules measured 0.23 to 0.28 mm., with a mean of 0.25 mm.; in the third instar 16 measured 0.367 to 0.39 mm., with a mean of 0.375

mm.; and in the fourth instar 15 head capsules measured 0.525 to 0.61 mm., with a mean of 0.56 mm.

The mature larva is 5.8 to 7.9 mm. in length and averages 6.45 mm. It is ultra ash gray with dark-purple spots (fig. 3, *B*).

The pupa is apple green when first formed, later turning to a brown typical of lepidopterous pupae commonly found in the soil (fig. 3, *C*). Keifer (*9*) has described the larva and pupa of this species in detail.

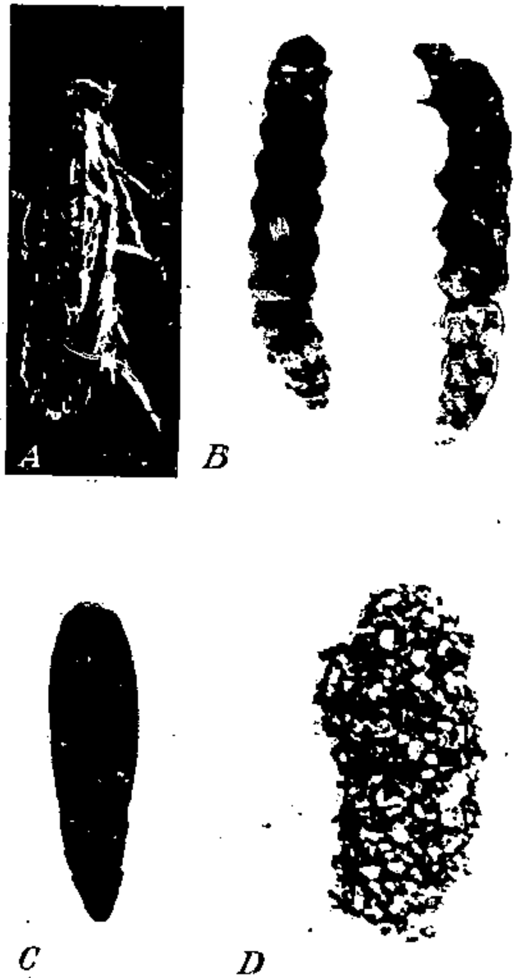

FIGURE 3.—Stages of the tomato pinworm: *A*, Adult, × 6; *B*, larvae, × 9; *C*, pupa, × 8; *D*, pupal cell formed of soil particles, × 8.

SEASONAL HISTORY

In California, development of all stages may continue, but at a retarded rate, during winters when tomato vines survive. Ordinarily, however, the tomato pinworm spends the winter in the pupal stage at or near the surface of the soil. During March and April the moths emerge to mate and lay eggs on the leaves of the young plants. Larvae hatching from the eggs mine the leaves during about half their larval existence, or during the first two instars. At the beginning of the third instar the larvae, having become too large to continue as true leaf miners, emerge from their mines and form leaf folds. Infestations are usually light on young plants early in the season, but as the season advances a gradual build-up is apparent. As the fruits set a few larvae enter them instead of folding the leaves. The number of larvae entering the fruits increases as the pinworm population multiplies, until a large proportion of the fruits may become infested. In cases of heavy infestations leaf injury may also become conspicuous.

When the larvae become mature in leaf folds or on the fruit they lower themselves by silken threads to the ground, where they form loosely woven pupal cells intermingled with particles of soil (fig. 3, *D*). Moths emerge from these pupal cells later to mate, lay eggs, and repeat the cycle. During fall and winter, as temperatures decrease, pinworm development is greatly retarded, or it may cease altogether except for the survival of pupae in the soil and moths in protected places.

The rapid development of the pinworm in summer together with the comparatively long oviposition period soon obscures any indication of definite broods in the field. Seven to eight generations have been reared during a year, of which four or five occurred during the summer months.

The transportation of infested fruit is the most common means of tomato pinworm dissemination. Other important means include the flight of moths within and between tomato fields and the transportation of infested seedling plants and picking and packing boxes from pinworm-infested localities.

The sources of infestation each year in an area where the pinworm has become established are worthy of note because of their bearing on control. Fields in which tomatoes have been grown are often left undisturbed after the last picking, and many of the plants may continue in various conditions of growth. Pinworm development continues in such fields if the temperature permits the survival and growth of tomato plants. Larvae in the leaf-mining and leaf-folding stages occur in large numbers on overwintering plants during mild winters in southern California, and are the cause of serious damage in new fields the following spring. If low temperatures in the winter kill the plants, pinworms which are pupating in the soil are often able to span the remaining period and emerge during the early growth stages of the new tomato crop. The insect may also survive in seedbeds or in propagating houses and may infest the new crop.

Tomato plants are often cut or pulled after harvest, and piled along the edge of the field to make way for a second crop. Pinworm moths flying from these plant piles cause serious infestations of late-fall or early-spring tomato crops.

THE ADULT STAGE

Materials and Methods for Study

Studies were carried on under outdoor insectary conditions by observing individuals placed on small tomato plants growing in 6-inch pots. Small celluloid and lantern-globe cages were used to cover the plants. Oviposition records were obtained by confining pairs of moths in small celluloid cages over tomato twigs arranged in small wine glasses. In all cases the food material for the moths refers to a 10-percent honey solution. Unfed moths were given only water. Some general observations and special studies were made in the field as indicated. All temperature records refer to air temperatures as obtained in a standard weather-instrument shelter.

Adult Behavior

After emergence from the pupal cell, the habits of the pinworm moth are similar to those of a near relative, the potato tuber moth (*Gnorimoschema operculella* (Zell.)), as given by Graf (7). The manner of rapid erratic flight when disturbed and that of hiding during the day appear to be habits common to both species. The coloration of the pinworm moth fits it well for its existence in the field. The presence of hundreds of moths per plant may not be suspected during the day until some disturbance causes them to fly up in a rapid, fitful manner, only to alight and hide again a few feet away. The moths, which are nocturnal, begin flight and oviposition at twilight and continue to oviposit through the night if the temperature is about 60° F. or above. Activity is accelerated by an increase in temperature.

The proportion of sexes during the year appears to be about constant, 54.8 percent females and 45.2 percent males. In connection with life-history studies, the sex of 347 moths was determined. The number of females exceeded that of males only slightly at all seasons except during the winter months, when there were 33 males and 24 females in a sample of 57 moths. Mating occurs within 24 to 48 hours after emergence.

Pinworm moths are attracted to lights. They have been observed in numbers around lights in greenhouses and at automobile lights, and have been collected easily at trap lights in the field.

Longevity of the Moths

The longevity of the pinworm adults has been determined by observing the time of emergence and death of a large number of moths at temperatures ranging from 50° to 80° F. Moths lived an average of 7 days at mean temperatures of 76° to 80° when given only water, but to an average of 8.5 days when fed a 10-percent honey solution. At temperatures of 50° to 55° the respective longevities were 20.5 and 22.8 days.

Oviposition

The moths, when confined to small cages under laboratory conditions, deposit eggs indiscriminately on all parts of the plants and on the cages. The eggs are so small and inconspicuous that very few have been observed in the open field. The few eggs that have been found, five or six in all, were on the tomato leaves.

Oviposition in the field was studied by liberating 50 moths in each of 4 cages 14 by 14 by 19 inches set over small tomato plants that were bearing fruit. The cages were set up on 4 different dates during

August and September 1935. The plants were taken up after 3 or 4 days of exposure to the moths and examined bit by bit under a low-power binocular microscope. Ninety-eight eggs were found, 45 percent of which were on the upper surface of the leaves and 53 percent on the lower surface. The other 2 percent were on the leaf petioles. Seventy-nine percent of the eggs were found on the upper 12 inches of the plants and 42 percent on the upper 6 inches. It appears, therefore, that under normal conditions most of the eggs are laid on the upper leaves of the plants.

The effect of temperature and food on oviposition was noted by observing egg deposition of fed and unfed groups of moths during the summer months and of a fed group during the winter (table 1). During the summer 44 unfed moths laid their eggs sooner after emergence than 12 fed moths but laid only 45 percent as many. Unfed moths laid twice as many eggs each the first night as the fed moths, but the fed moths continued laying for 16 days, whereas the unfed moths laid eggs for only 8 days. Lower mean temperatures—of 50.6° F. from October 8 to December 27 compared with a mean of about 69° F. during the summer—merely retarded the rate and prolonged the period of oviposition. In all cases the peak of oviposition was reached on or before the second night after emergence. In general, during the summer, the moth begins egg laying the first or second night after emergence and lays most of her eggs in a few days.

TABLE 1.—*Oviposition data for 3 groups of tomato pinworm moths, showing effect of food and temperature, Alhambra Calif., 1935*

Night after moth emergence	Moths ovipositing			Average eggs per female			Proportion of total eggs laid		
	A [1]	B [2]	C [3]	A	B	C	A	B	C
	Percent	*Percent*	*Percent*	*Number*	*Number*	*Number*	*Percent*	*Percent*	*Percent*
First	59.0	58.3	12.5	25	12	2	31.7	12.0	0.3
Second	79.5	100.0	62.5	23	18	31	43.3	19.1	21.4
Third	47.7	90.0	75.0	10	15	16	11.7	11.5	15.7
Fourth	68.3	90.0	50.0	3	14	3	4.3	11.1	2.1
Fifth	11.8	83.0	50.0	8	11	19	2.1	9.8	12.1
Sixth	6.8	75.0	37.5	6	12	8	1.7	10.0	4.0
Seventh	9.1	83.0	75.0	4	9	9	.9	7.7	8.2
Eighth	6.8	75.0	75.0	9	9	8	1.3	6.9	7.8
Tenth		66.6	75.0		4	9		4.0	8.7
Twelfth		33.3	50.0		3	4		1.5	2.7
Fourteenth		16.6	75.0		1	8		.2	7.2
Sixteenth		8.3	37.5		1	5		.2	2.5
Eighteenth			12.5			2			.3
Twentieth			25.0			6			1.9
Twenty-second			25.0			2			.8
Twenty-fourth			25.0			4			1.5
Average				42	91	79			
Total				1,851	1,122	628	100	100	100

[1] A, 44 Moths given water only. June 22 to September 10. Mean temperature, 69.8° F.
[2] B, 12 Moths given 10-percent honey solution. September 9 to September 27. Mean temperature, 68.9° F.
[3] C, 8 Moths given 10-percent honey solution. October 8 to December 27. Mean temperature, 50.6° F.

THE DEVELOPMENTAL PERIOD

The duration of the developmental period of the pinworm was studied under different temperature conditions by rearing individuals separately in outdoor insectary cages. The observations were begun on April 25, 1935, and 25 to 50 newly laid eggs were selected every 10 days, until April 16, 1936, except during the cooler months, when the intervals were lengthened to as much as 30 days.

As the eggs hatched the larvae were isolated for individual records on small tomato plants growing in 6-inch flowerpots and covered with small cages. In all 398 individuals were observed in this manner.

As shown in table 2, only 26.4 days were required for development at temperatures averaging from 76° to 80° F., whereas 99.7 days were required at temperatures averaging from 50° to 55°.

TABLE 2.—*Duration of various stages in the developmental period of the tomato pinworm reared under outdoor insectary conditions at different mean temperatures, Alhambra, Calif., April 25, 1935, to April 16, 1936*

Mean temperature (°F.)	Incubation period		Leaf-mining stage		Leaf-folding stage		Prepupal and pupal stages		Total developmental period	
	Individuals observed	Average period	Individuals observed	Average period	Individuals observed	Average period	Individuals observed	Average period	Individuals observed	Average period
	Number	*Days*	*Number*	*Days*	*Number*	*Days*	*Number*	*Days*	*Number*	*Days*
50-55	60	20.3	43	24.7	28	16.0	66	38.7	49	99.7
56-60	87	11.3	37	14.3	27	11.7	0		0	
61-65	80	8.6	116	10.1	137	7.7	107	17.8	110	41.2
66-70	63	6.6	90	7.5	118	5.9	107	12.8	94	32.8
71-75	67	5.6	14	9.0	48	4.5	78	11.0	52	30.1
76-80	41	5.2	63	5.5	18	4.3	23	11.4	36	26.4
81-85	0		18	5.8	5	5.6	0		0	

The incubation period required an average of 5 to 6 days under summer conditions. Winter temperatures greatly delayed hatching. Additional records (table 3) show that eggs will develop and hatch in a minimum of 4 days and that under winter conditions a maximum of 30 days may be required. Eggs developed at average temperatures as low as 50° and as high as 81° F.

TABLE 3.—*Incubation period of eggs of the tomato pinworm in relation to temperature, Alhambra, Calif., 1935–36*

Mean temperature (°F.)	Eggs observed	Incubation period		
		Minimum	Maximum	Mean
	Number	*Days*	*Days*	*Days*
46-50	82	20	30	25.7
51-55	209	18	29	22.3
56-60	491	10	11	11.5
61-65	1,109	7	11	8.5
66-70	724	5	8	6.5
71-75	312	4	8	5.4
76-80	60	4	5	4.8
81-85	82	4	4.5	4.3

Insectary conditions afford an opportunity to make more accurate observations of detailed life history than are possible under field conditions, but the duration of all stages may not be quite the same in the two environments. Since the tomato pinworm pupates at or near the surface of the soil, the duration of the period in the soil is likely to be greatly affected by variations in air temperature. An experiment was therefore designed to determine the duration of the quiescent period in the soil for three winter seasons. This was done by trapping pinworm larvae as they left infested fruit to pupate and introducing specified numbers of them into cages set on the soil. Moths were collected as they emerged. The duration of the prepupal and pupal stages was longer under these conditions than under laboratory conditions. This was particularly true where the minimum temperature was below 32° F. Detailed data are given in table 4.

TABLE 4.—*Duration of the period between the introduction of mature larvae of the tomato pinworm into outdoor cages and the emergence of adults as related to minimum and mean temperatures, Alhambra, Calif.*

Date of introduction	Temperature of air during test		Individuals in test		Duration of period in soil	
	Minimum	Mean	Introduced	Emerged	Range	Mean
1934	*° F.*	*° F.*	*Number*	*Percent*	*Days*	*Days*
Nov. 1-4	36	56.6	152	23.7	42- 58	48.5
5-6	31	53.7	350	22.8	41- 87	56.5
Nov. 29-Dec. 3	31	56.1	100	6.0	39- 70	56.0
Dec. 17-19	31	51.8	250	8.9	50- 70	64.8
1936						
Nov. 5-9	22	51.8	200	31.5	23- 69	31.5
10-14	22	49.8	600	36.7	29- 93	45.7
15-19	28	52.8	300	7.0	39- 53	40.7
25-30	22	49.4	300	31.3	87-122	97.8
Dec. 1-9	22	47.8	414	8.4	78- 95	88.6
10-15	22	47.8	447	0		
18-23	22	48.4	126	3.2	60-102	70.5
1937						
Nov. 24	34	60.7	400	44.8	33- 57	39.9
Dec. 3-6	34	51.8	400	25.5	39- 61	48.8
11-14	32	50.9	400	11.2	40- 75	60.3
20-23	32	50.8	400	21.5	47- 71	58.4
Dec. 28-Jan. 3	32	51.0	200	31.0	53- 69	59.4
1938						
Jan. 5-7	32	50.7	300	28.0	18- 65	40.5
13-20	32	50.8	337	18.1	18- 63	52.4
25	32	50.7	94	29.8	43- 60	48.8

LARVAL HABITS

Leaf Mining

On hatching from the egg, the minute larva moves about for a few minutes before beginning to mine in a leaf. It then forms a tent of silk and under this it enters the leaf to form either an upper-surface or a lower-surface mine. Many mines are of the serpentine type, whereas others are almost straight (fig. 1, *A* and *B*). As the larva develops, the tunnel is enlarged to full thickness of the leaf and is widened to the blotch type of mine (fig. 1, *C*). The removal of the mesophyll causes the epidermis on both upper and lower surfaces to appear transparent. After entering the leaf, the larva ejects its frass into the web at the entrance, which forms a small dark mass (fig. 1, *B*). Newly formed mines are characterized by this dark spot. The tent, together with a small section of the mine at its beginning, is used as a retreat during the leaf-mining period. Typical mining also occurs commonly in the calyx lobes and occasionally on the surface of the fruit.

Leaf Folding

The tomato pinworm, like other members of the family Gelechiidae, is not highly specialized for the leaf-mining type of life. Needham, Frost, and Tothill (*16*) refer to leaf-mining members of this family as "borderline forms, leaf-mining being mixed with other habits." After spending two instars or about half of its larval life as a leaf miner, the pinworm larva emerges from the mine to form a protective leaf fold (fig. 1, *C* and *D*), usually in another part of the same leaf unless it has been largely consumed. This is accomplished by spinning a silken web across the surface, which gradually draws it into a fold. Of a group of 142 larvae observed individually on the leaves of potted plants, 64 percent folded the leaf that had been mined, 28 percent left the original leaf and folded another, 5 percent drew 2 leaves together, and 3 percent bored into the plant stem.

The manner of feeding is not materially changed during the leaf-folding period. Larvae continue to feed on the mesophyll of the leaf but form large blotch mines which often cover the larger part of the leaf. The leaf fold forms a retreat, or shelter, from which the larva crawls to feed between the more or less transparent upper and lower surfaces of the leaf. In the greenhouse 78 percent and in the field 89 percent of the larvae observed folded over the upper surface of the leaf.

Observations were made of each of 116 larvae during their leaf-mining and leaf-folding periods. They injured a total of 305 leaflets, or an average of 2.6. Each of 3 larvae injured 6 leaflets.

Larval Attack on the Fruit

The calyx lobes of tomatoes are commonly mined in the same manner as are the leaves. Larvae that have mined the calyx lobes, and some of those from leaves near the fruit, bore into the fruit at the time leaf folding would ordinarily occur. The exact origin of all larvae that enter the fruit is not known, but the examination of a number of infested tomatoes in the field throws some light on the question. In 13 of 20 tomatoes from a heavily infested field, from 1 to 6 of the calyx lobes of each one had been mined. There were a total of 33 mined calyx lobes out of a possible 120, and 47 larvae had entered the 20 tomatoes. Of these larvae 20 were third instars and 27 were either fourth instars or had left the fruit to pupate. Seven out of 20 of the infested fruit examined had no evidence of mining in the calyx lobes. Larvae usually enter the fruit beneath the calyx or the stem, yet these examinations showed that there were 26 entrance holes in other places as well.

These data lead to the following conclusions: (1) That larvae enter the fruit at the beginning of the third stadium, (2) that a large percentage of the larvae that attack the fruit go directly into the fruit from their mines in the calyx lobes, and (3) that a substantial number of the larvae that attack the fruit come from leaves near the fruit.

PUPATION

Pupation occurs at or near the surface of the soil. A few exceptions to this have been recorded, but these have been rare. Swezey

(*17*) reported pupation in tomato leaves in Hawaii, and the authors have occasionally observed pinworm pupae in leaf folds, in the fruit, and on the sides of breeding cages. Thomas (*18*) reports similar observations under greenhouse conditions in Pennsylvania.

The actual depth of pupation has been investigated by sifting the soil beneath several plants in the field and by setting up experiments comparable to field conditions. In the field, all of 627 pupae recovered were within 1½ inches of the surface, 98 percent within 1 inch, and 89 percent within ½ inch. In previously sifted soil beneath baskets of infested tomatoes, 215 pupae were recovered. All these were within ½ inch of the surface and 69 percent were on the surface.

In other experiments prepupal larvae and pupae were buried at different depths in soil in 6-inch flowerpots to determine if the insect could survive the pupal stage if buried. The percentages of normal moths emerging in these tests were 66, 4, 2, 0, and 0 from the soil surface and from depths of 1½, 2, 2½, and 3 inches, respectively.

Two badly injured moths emerged from pupae buried at 2½ inches. Since pinworm moths were not able to emerge normally when larvae were buried 2 or more inches in the soil, it is probable that turning under the surface soil to greater depths by plowing would be an effective measure of control.

NATURAL ENEMIES

Parasitization of the tomato pinworm in leaf folds and in the fruit is common. Swezey (*17*) reported 50 percent larval parasitization by *Angitia blackburni* Cam. in Hawaii. Thomas (*19*) lists *A. ferrugineipes* (Ashm.), *Microbracon junicola* (Ashm.), and *Apanteles epinotiae* Vier. as parasites of the pinworm in Pennsylvania. Out of 342 prepupal larvae placed in pupation racks at Alhambra, Calif., during November and December, 1935, 46 percent were parasitized. The following parasites were determined from those emerging: *Apanteles scutellaris* Mues., *Sympiesis stigmatipennis* Girault,[5] *Chelonus phthorimaeae* Gahan, *Campoplex phthorimaeae* (Cush.), and a new species of *Angitia*.[6]

Other species of parasites reared from tomato pinworm larvae collected from various localities in California are *Hormius pallidipes* Ashm.,[7] *Angitia ferrugineipes* (Ashm.),[6] *Tetrastichus* sp.,[5] and *Apanteles dignus* Mues. The last was described from material reared from tomato pinworm larvae from Santa Ana, Calif., in 1936 (*15*). From collections of tomato leaf folds placed in emergence cages in the laboratory the following parasites emerged: *Zatropis* sp., *Catolaccus aeneoviridis* (Gir.), and *Chrysocharis* sp.[8]

An examination of leaf folds in two fields in Orange County, Calif., in October 1936 revealed that 41 percent of the leaf folders were parasitized. Parasitization of larvae in the fruit was observed commonly in these fields. Parasites have undoubtedly been an important factor in the gradual decrease in pinworm abundance since about 1936, the period of maximum abundance, until 1941, when a low point in degree of pinworm injury was reached.

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[5] Determined by P. H. Timberlake.
[6] Determined by R. A. Cushman.
[7] Determined by C. F. W. Muesebeck.
[8] Determined by A. B. Gahan.

UNDESIRABLE CULTURAL PRACTICES

The most important cultural practice contributing to pinworm development and survival is the prevalent manner of handling tomato plants after the marketable fruit has been removed (*6*). These plants, which are usually heavily infested by pinworm larvae in all stages of development, still carry a large number of infested fruits. To hasten the preparation of the soil for a new crop, in areas where more than one crop per season is possible, these plants may be cut and piled along the edge of the field or on adjoining unused land. Pinworm larvae as they mature leave the piled-up plants to pupate in the soil and trash surrounding and beneath them. Many immature larvae which are forced to leave the foliage as it dries are able to complete development in the fruit left on the plants, which often remains sound for several weeks. In an effort to determine just what effect these old plants have on pinworm survival, some of these plants were covered with large cages to trap the moths that emerged. By frequent examination of the cages it was found that moths continued to emerge from the old plants for 4 months after their removal from the field in November 1934. These moths oviposited readily when taken to the laboratory.

Old plants were also brought to Alhambra at intervals during the period when plants were usually taken from the field and placed, five to a cage, in a number of screen cages. A record of moth emergence from the plants in the cages was kept. As shown in table 5, the period from the date the plants were taken from the field until the last moth emerged ranged from 78 to 136 days.

TABLE 5.—*Emergence of tomato pinworm moths from cages when 5 heavily infested plants carrying a small amount of fruit left on the plants after harvest were placed in each emergence cage at Alhambra, Calif., 1934–35*

Cage No.	Temperature of air during test	Date of plant introduction	Moth emergence period		Total moths emerged	Total period from plant introduction to last moth emergence
	F.			*Days*	*Number*	*Days*
1	58.3	Oct. 3	Oct. 29–Dec. 21	53	115	79
2	57.5	do	Oct. 29–Jan. 7	70	308	96
3	57.8	Oct. 23	Nov. 2–Jan. 23	82	213	92
4	53.6	Nov. 3	Nov. 9–Feb. 22	105	335	111
5	52.8	Nov. 14	Nov. 19–Feb. 12	85	110	90
6	52.4	Nov. 26	Nov. 27–Apr. 11	135	39	136
7	52.3	Dec. 10	Dec. 17–Feb. 26	71	12	78
8	51.5	Jan. 4	Jan. 10–Mar. 28	77	53	83
Average	54.5			84.7		95.6

A practice even more favorable to pinworm survival is that of leaving the old vines unmolested after the marketable crop has been picked. The plants in such fields often remain in various conditions of growth throughout the winter or for long periods during the active growing season. As long as green foliage or fresh fruit remain in such fields the pinworm is able to continue development. Moths have frequently been observed emerging from the soil in such fields for several weeks after new crops had been set out in adjoining fields—in one case at the rate of 5 per plant to go to a tomato field which had been set out 15 days previous.

Other practices favorable to pinworm survival and dissemination are the careless disposal of infested culled fruit and the use of infested seedling plants.

LABORATORY INSECTICIDE TESTS

A laboratory method of testing the relative effectiveness of various insecticides preliminary to their use in the field consisted of the uniform treatment of potted tomato plants carrying 10 pinworm larvae per plant. The larvae when 3 or 4 days old were transferred to potted plants. More than 10 were placed on each plant and then an attempt was made to remove all of them except 10 before treatment. Insecticides were applied uniformly by using a small dust blower from which 0.2 gram of dust was delivered each time by blowing it all out. This duster (fig. 4) consisted of a tube from a small dust blower

FIGURE 4.—Small duster from which a weighed quantity of dust is blown. The dust was confined to a definite area around the plant by a tall glass cylinder supplemented by a pasteboard cylinder.

attached to a cork which fitted a burette cap. The dust was confined to a definite area around the plant by an 11½-inch cylinder. The plant was supported on a rotating phonograph turntable during treatment. The uniformity of treatment was tested frequently by exposing weighed glass slides at plant height which were reweighed to determine the dust deposit. On 9 slides thus exposed, the deposit of dust ranged from 108 to 150 micrograms per square centimeter.

The plants were treated just before the larvae were due to leave their mines to form leaf folds. About 10 days later, or when the larvae left the plants to pupate, they were trapped and counted. This was done by arranging over each plant a No. 2 lantern globe supported by a small plywood platform covered with paper which was sealed around the plant with gummed paper and cotton (fig. 5).

FIGURE 5.—Method of trapping the tomato pinworm larvae leaving the plants to pupate. The paper was completely sealed around the plant by a strip of gummed paper tape.

The insecticides tested were derris root containing 2.0 percent of rotenone and 11.8 percent of ether extractives; conditioned cuprous cyanide containing 84 percent of cuprous cyanide; unconditioned cuprous cyanide containing 98.4 percent of cuprous cyanide; phenothiazine practically pure; natural cryolite containing 90 percent of sodium fluoaluminate; imported synthetic cryolite containing 93 percent of sodium fluoaluminate; lead arsenate; sulfur nitride, a laboratory-prepared sample; calcium arsenate, an undiluted commercial material; copper cyanamide, a commercial material containing 34.4

percent of copper cyanamide diluted with gypsum; pyrethrum, an extract-impregnated dust containing 0.34 percent of pyrethrin I and 0.49 percent of pyrethrin II; and devil's shoestring containing 1.7 percent of rotenone and 7.5 percent of carbon tetrachloride extractives. All dilution percentages later mentioned refer to the amount of active chemical unless noted otherwise.

The survival of pinworm larvae on 17 groups of 5 untreated plants each used as checks during these tests ranged from 43 to 53, with a mean of 47.5, the standard of error of which was 0.6. The expected number of survivors was 50 larvae per group of 5 plants, but owing to failure in reducing the number to 10 in some cases an extra one occurred occasionally. Larval survival was therefore sufficiently uniform to serve as a basis for insecticide tests.

Table 6 shows a summary of the tests when the plants were treated by the method described. One striking feature of these results is the low effectiveness of lead arsenate and calcium arsenate compared with that of cryolite.

TABLE 6.—*Reduction in number of tomato pinworm larvae at the time they left the caged plants to pupate, after each plant, carrying a population of 10 larvae, had been treated with 0.2 gram of insecticide. Alhambra, Calif. General insecticide tests, 1936*

Insecticide	Larvae used	Reduction in number of larvae
	Number	*Percent*
Imported synthetic cryolite and talc dust (50 percent sodium fluoaluminate)	200	86
Natural cryolite and talc dust (50 percent sodium fluoaluminate)	120	94
Derris, talc, and sulfur dust (0.8 percent rotenone, 25 percent sulfur)	100	91
Conditioned cuprous cyanide and talc dust (30 percent $Cu_2(CN)_2$)	120	92
Conditioned cuprous cyanide and talc dust (20 percent $Cu_2(CN)_2$)	120	89
Domestic synthetic cryolite and talc dust (33 percent sodium fluoaluminate)	210	79
Phenothiazine and talc dust (10 percent phenothiazine)	150	78
Derris and talc dust (0.8 percent rotenone)	200	73
Devil's shoestring and talc dust (0.8 percent rotenone)	100	68
Calcium arsenate	150	50
Lead arsenate and talc dust (50 percent lead arsenate)	100	45
Copper cyanamide	50	20
Pyrethrum (20 percent (PI 0.34, PII 0.49))	50	18
Sulfur nitride and talc dust (0.5 percent sulfur nitride)	60	18
Sulfur, 350 mesh	100	18
Difference required for significance at odds of 19:1		11
SPECIAL TESTS WITH NATURAL CRYOLITE		
Percentage of active material:		
8.2	120	69
12.6	60	87
18.6	120	92
27.9	120	94
37.2	120	95
46.5	120	94
55.8	120	97
Difference required for significance at odds of 19:1		10
SPECIAL TESTS WITH CUPROUS CYANIDE		
Percentage of active material:		
5	120	65
10	120	81
15	120	87
20	120	88
30	120	92
Difference required for significance at odds of 19:1		10

FIELD INSECTICIDE TESTS

Materials and Methods

Field insecticide tests were begun in 1936 and continued through 1941. Improvements in experimental design and in methods of evaluating the results of control were adopted from year to year. The insecticides included contact and stomach poisons in both spray and dust forms.

The following contact insecticides were used: A medium summer oil (65 seconds Saybolt viscosity at 100° F.), an oil emulsion (63 seconds Saybolt viscosity at 100° F.), commercial nicotine sulfate containing 40 percent of nicotine, a commercial pyrethrum preparation containing 2 percent of pyrethrins in the form of a solution in oil coated upon a dust material, pyrethrum extract containing 2 cc. of pyrethrins to 100 cc., a thiocyanate (BB′ butoxy thiocyanodiethyl ether), and 350-mesh sulfur.

The following stomach poisons were tested: Natural cryolite containing 90 percent of sodium fluoaluminate; imported synthetic cryolite containing 93 percent of sodium fluoaluminate; domestic synthetic cryolite containing 83 percent of sodium fluoaluminate; unconditioned cuprous cyanide containing 98.4 percent of cuprous cyanide; conditioned cuprous cyanide with a deflocculating agent added during manufacture, containing 84 percent of cuprous cyanide; copper cyanamide, a crude material containing 21.3 percent of copper and 65.3 percent of gypsum; calcium arsenate, a common commercial brand; phenothiazine, practically chemically pure; powdered cube or derris root containing approximately 5.0 percent of rotenone and 26.4 percent of total extractives; and cube or derris extract containing 2 percent of rotenone. A red cuprous oxide containing 96.5 percent of Cu_2O was used as a fungicide, in combination with cryolite where indicated.

Most of the dust mixtures contained a single diluent, 400-mesh talc. In specific cases other diluents were used with talc. These diluents consisted of a light, finely ground diatomaceous earth, walnut-shell flour, and redwood-bark flour.

Spraying was necessary in testing certain liquid insecticides. Some dust materials were just as effective when used in a liquid medium, but dusting was found to be more economical than spraying.

The dusts were applied to plots about one-tenth acre in size in 1936, 1937, and 1938, one-twentieth acre in 1940, and one-fortieth acre in 1941. Rotary hand dusters (fig. 6) were used. In each experiment conducted in the first 3 years 4 or 5 replicates were made in each field; whereas in 1940 and 1941 from 10 to 12 were used. In all experiments the dust treatments were assigned to the plots by the randomized-block method. The plants were thoroughly covered at each application, although this required dusting from both sides of each when the plants became large.

The sprays were usually applied at a pressure of 350 pounds to long, narrow plots six or more rows wide by means of a three-row horse-drawn power sprayer (fig. 7) equipped with four nozzles to each row. Except in the Irvine field B, only one or two replicates were made of

FIGURE 6.—Dusting tomatoes with a rotary hand duster for tomato pinworm control.

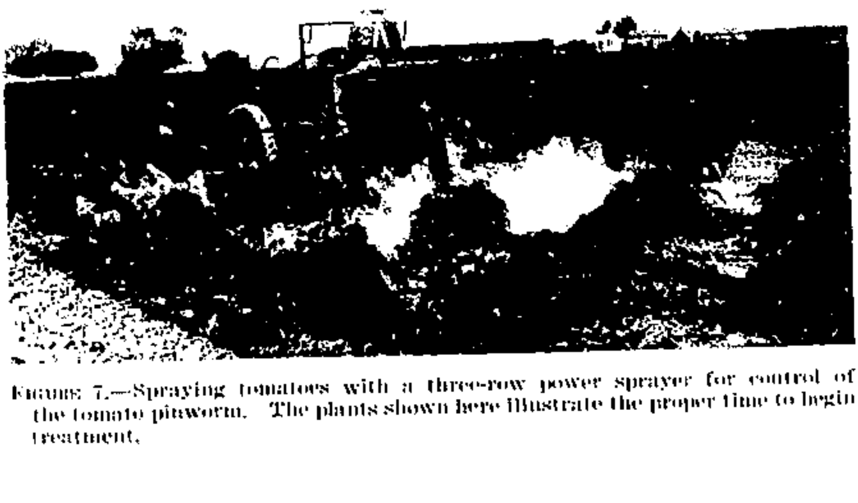

FIGURE 7.—Spraying tomatoes with a three-row power sprayer for control of the tomato pinworm. The plants shown here illustrate the proper time to begin treatment.

the treatments applied by the power sprayer. In one field four replicates were made with hand sprayers on one-tenth-acre plots.

The first general plan of tomato pinworm control was to make three or four applications of insecticides during the fruit-setting period at about 14-day intervals. This usually placed the last application 1 to 2 weeks before the first picking. Variations from this schedule were an extra application on the young plants before the fruit began to set, or one application after the first picking. In some cases applications were made at 10-day intervals.

Before 1940 all or part of the fruit from the central area of each plot was examined, and the percentage of fruit injured by the tomato pinworm was tabulated without regard to other injuries which might have made the fruit unfit for market. During 1940 and 1941 four and five plants, respectively, were staked near the center of each plot, and all the fruit as it ripened was picked from them and examined as a basis for results of control. The results were then expressed, as before, in percentages of fruits injured, and finally in percentage reduction of injury in treated plots as compared with untreated plots. Whenever percent control is mentioned it refers to this relationship. Any further details concerning methods or materials are discussed prior to giving the results of control for each year.

Experiments of 1936

In 1936 derris-talc dust containing 0.75 percent of rotenone, conditioned cuprous cyanide-talc dust containing 20 percent cuprous cyanide, natural cryolite-talc dust containing 50 percent sodium fluoaluminate, and phenothiazine-talc dust containing 20 percent phenothiazine were applied three times, 12 days apart, to a very heavily infested tomato field. Thirty-six percent of the small green fruit as well as most of the leaves were infested before treatment began. On four replicates treated with each material the average degree of fruit injury ranged from 42 to 57 percent after insecticide treatment. Some degree of control was indicated in the cryolite and cuprous cyanide plots, but the difference was not significant. No control was indicated in the derris and phenothiazine plots. In addition to the fact that tomato pinworm infestations such as this are difficult to control, the treatments did not protect the plants over a sufficiently long period. Later experience has led to the conclusion that one early insecticide application on the young vines and another after picking began, in addition to the three applications made, would have been required to control the tomato pinworm under these conditions.

Experiments of 1937 and 1938

In 1937 the treatments were made on 218 field plots, or 35 acres; and the next year 330 plots, totaling 42 acres, were used. Part of the results of these insecticidal treatments are presented in table 7. Some experiments have been omitted from the table because of a lack of pinworm abundance; others, because of inconclusive results or insufficient data. All treatment applications in 1937 and 1938 were made at 14-day intervals during the period from fruit setting to 10 to 14 days preceding the first market picking.

TABLE 7.—*Injury to tomato fruits by the tomato pinworm in California following various insecticidal treatments in 1937 and 1938*

IRVINE FIELD A, SANTA ANA, HAND SPRAYERS AND DUSTERS USED, 4 APPLICATIONS, 1937

Insecticide	Rate per acre per application		Replicates	Fruits examined	Fruits injured	Control based on check
	Pounds	*Gallons*	*Number*	*Number*	*Percent*	*Percent*
Conditioned cuprous cyanide, talc dust (16.8 percent $Cu_2(CN)_2$)	12	----	4	1,334	0.7	81
Conditioned cuprous cyanide, water (3 pounds to 100 gallons)		25	4	1,469	1.1	70
Natural cryolite, talc dust (45 percent Na_3AlF_6)	11	----	4	1,692	1.2	68
Phenothiazine, talc dust (15 percent phenothiazine)	13	--	4	1,779	2.0	46
Phenothiazine, water (3 pounds to 100 gallons)		25	4	1,886	2.7	27
Nicotine sulfate, whale-oil-soap, water (1 pint, 1 pint, 75 gallons)		25	4	1,591	2.8	24
Pyrethrum, talc dust (0.16 percent total pyrethrins)	9	-	4	1,819	2.9	22
Pyrethrum extract, water (1-300 by volume) 0.020 percent total pyrethrins		25	4	1,858	3.3	11
Thiocyanate, water (1-100 by volume)		25	4	1,927	4.5	−22
Calcium arsenate, lime dust (50 pounds, 50 pounds)	7	--	4	1,416	5.5	−49
None	----	----	5	2,298	3.7	------
Difference required for significance at odds of 19:1	----	------	----	------	2.0	----------

IRVINE FIELD B, SANTA ANA, HAND DUSTERS AND A POWER SPRAYER USED, 3 OR 4 APPLICATIONS,[1] 1938

Insecticide	Rate per acre per application		Replicates	Fruits examined	Fruits injured	Control based on check
	Pounds	*Gallons*	*Number*	*Number*	*Percent*	*Percent*
Conditioned cuprous cyanide, talc (30 percent $Cu_2(CN)_2$)	14.4		4	1,410	1.6	84
Conditioned cuprous cyanide, talc (20 percent $Cu_2(CN)_2$)	9.5		4	1,030	1.7	83
Unconditioned cuprous cyanide, talc (30 percent $Cu_2(CN)_2$)	11.3		4	1,080	2.2	78
Unconditioned cuprous cyanide, talc (20 percent $Cu_2(CN)_2$)	9.5		4	1,160	3.4	67
Natural cryolite, talc (50 percent Na_3AlF_6)	12.0		4	1,130	3.7	64
Phenothiazine, water (3 pounds, 100 gallons)		88	4	940	3.8	63
Cube, diphenyl-butyl sodium sulfonate, water (2½ pounds, 2 ounces, 100 gallons)	--	97	4	1,080	4.1	60
Domestic synthetic cryolite, talc (50 percent Na_3AlF_6)	10.0		4	1,310	4.1	60
Copper cyanamide dust (undiluted)	11.5		4	1,070	4.7	54
Natural cryolite, talc (30 percent Na_3AlF_6)	10.0		4	1,170	5.5	46
Cube root, peanut oil, triethanolamine, oleate, water (2½ pounds, 1 gallon, 43 ounces, 100 gallons)	-	92	4	1,000	5.8	43
Domestic synthetic cryolite, talc (30 percent Na_3AlF_6)	10.6		4	1,270	6.2	39
Imported synthetic cryolite, talc (30 percent Na_3AlF_6)	12.0		4	1,090	6.6	35
Cube, talc (0.75 percent rotenone)	7.7		4	1,115	7.4	27
None			12	3,546	10.2	
Difference required for significance at odds of 19:1					3.1	

YORBA LINDA FIELD B, YORBA LINDA, HAND EQUIPMENT USED, 4 APPLICATIONS

Insecticide	Rate per acre per application		Replicates	Fruits examined	Fruits injured	Control based on check
	Pounds	*Gallons*	*Number*	*Number*	*Percent*	*Percent*
Imported synthetic cryolite, talc (50 percent Na_3AlF_6)	9		4	1,411	9.7	67
Natural cryolite, red copper oxide, redwood-bark flour, talc (55.5 pounds, 6 pounds, 15 pounds, 23.5 pounds)	11		4	1,263	11.6	60
Domestic synthetic cryolite, talc (50 percent Na_3AlF_6)	8		4	1,281	12.0	59
Phenothiazine, talc (20 percent phenothiazine)	8		4	1,288	17.0	41
Conditioned cuprous cyanide (20 percent $Cu_2(CN)_2$)	9		4	1,563	17.4	40
Cube, talc (0.75 percent rotenone)	11		4	1,575	25.8	11
None			5	1,517	29.0	------
Difference required for significance at odds of 19:1			-------		9.0	------

[1] Two plots were treated 3 times and two plots were treated 4 times.

TABLE 7.—*Injury to tomato fruits by the tomato pinworm in California following various insecticidal treatments in 1937 and 1938*—Continued

WILLIAMSON FIELD C, RIVERSIDE, HAND EQUIPMENT USED, 5 APPLICATIONS[1]

Insecticide	Rate per acre per application		Replicates	Fruits examined	Fruits injured	Control based on check
	Pounds	*Gallons*	*Number*	*Number*	*Percent*	*Percent*
Conditioned cuprous cyanide, talc (20 pounds, 80 pounds)	18.5		10	5,047	2.7	79
Imported synthetic cryolite, diatomaceous earth, talc (50 pounds, 40 pounds, 10 pounds)	20.0		5	2,526	3.6	72
Natural cryolite, talc (40 pounds, 60 pounds)	19.0		5	2,444	4.4	66
Calcium arsenate, nicotine sulfate (92½ pounds, 7½ pounds)	19.5		5	3,187	4.8	62
Phenothiazine, talc (30 percent phenothiazine)	20.0		10	2,341	7.1	45
Calcium arsenate undiluted	18.0		5	3,101	7.9	38
None			10	6,762	12.8	
Difference required for significance at odds of 19:1					5.3	

[1] Treated by Mr. Wilcox for fruitworm control, checked for pinworm control.

The results of insecticidal treatment during 1937 and 1938 indicate that cryolite and conditioned cuprous cyanide were probably the most effective materials used against the tomato pinworm. Phenothiazine was just as effective in some cases, but not in all. Calcium arsenate was not so effective as cryolite or cuprous cyanide. Materials used in both dust and spray form were about equally effective in either medium. The contact insecticides, such as nicotine sulfate, pyrethrum, and a thiocyanate, were less effective than the stomach poisons. Oil did not increase the degree of control when used with cryolite.

The degree of control was less than is considered to be adequate when the number of injured fruit exceeded 25 percent in the untreated plots. The low degree of control is partly due to rapid pinworm development which tends to minimize the effect of poisons, especially after treatment has been terminated. This fact is illustrated by table 8, which shows the trend of a pinworm infestation during the picking season when the last insecticide application had been made 10 days before picking began. Although the increase in fruit injury is not always so great as this, the trend is the same except very late in the season when cool weather retards tomato pinworm activity. Insecticides are not usually applied near or during the picking season because of the danger of excessive poisonous residue on the fruit. In late tomato fields in California, which are those most commonly damaged by the tomato pinworm, the picking season usually comes during the hottest part of the summer. Since this insect is favored by hot, dry weather it builds up rapidly in numbers at a time when insecticides are not usually applied.

EXPERIMENTS OF 1939

Experimental fields used in 1939 were so badly damaged by a storm that not enough fruit was produced to give dependable results.

TABLE 8.—*The trend of fruit injury caused by the tomato pinworm listed by pickings in treated and untreated plots when the last insecticide application was made 10 days before the first picking, Garden Grove, Calif., 1938*

Picking date	Injured fruit in Treated plots	Injured fruit in Untreated plots	Control
	Percent	*Percent*	*Percent*
Aug. 31	1.2	4.3	72
Sept. 12	2.0	4.9	59
Sept. 20	3.0	7.8	62
Oct. 5	14.7	29.7	51
Oct. 12	13.6	28.0	51
Oct. 27	13.0	21.6	40
Average	7.9	16.0	56

EXPERIMENTS OF 1940

Experiments in 1940 consisted of the testing of 3 schedules of applications of each of 3 insecticidal mixtures as indicated in table 9. A total of 20 replicates were made of each of the 9 insecticidal treatments and the check treatment, there being 10 in each of 2 fields. Field B was 15 days later than field A but was only one-half mile away, and the 2 fields were treated as nearly the same as was practicable.

TABLE 9.—*Injury to tomatoes by the tomato pinworm following different schedules of application of different insecticides, Pacoima, Calif., 1940*

Insecticide dust applied	Schedule number	Dates of application: July	Aug.	Sept.	Oct.	Quantity of dust per acre—all applications	Cost of treatment per acre	Fruits injured per plant	Control based on check
PACOIMA FIELD A (PICKING BEGAN SEPT. 15)									
						Pounds	*Dollars*	*Percent*	*Percent*
Natural cryolite, talc (50 percent sodium fluoaluminate).	1	16	6, 20	3		120	15.16	10.2	62
	2		14, 27	3, 21		152	18.14	9.1	66
	3		20	3, 24	10	150	17.95	7.7	71
Natural cryolite, talc (70 percent sodium fluoaluminate).	1	16	6, 20	3		124	16.77	5.6	79
	2		14, 27	3, 24		152	19.66	6.9	74
	3		20	3, 24	10	142	18.63	8.5	68
Cuprous cyanide, talc (20 percent cuprous cyanide).	1	16	6, 20	3		108	18.01	10.5	61
	2		14, 27	3, 21		119	19.47	5.6	79
	3		20	3, 24	10	118	15.34	9.5	64
None (check)								26.6	
Difference required for significance at odds of 19:1								3.3	
PACOIMA FIELD B (PICKING BEGAN SEPT. 30)									
Natural cryolite, talc (50 percent sodium fluoaluminate)	1		2, 16, 30	20		83	11.72	17.0	57
	2		24	10, 20	11	99	13.21	9.8	75
	3		30	20	11, 25	101	13.58	15.0	62
Natural cryolite, talc (70 percent sodium fluoaluminate)	1		2, 16, 30	20		82	12.45	14.4	64
	2		24	10, 20	11	97	13.09	8.8	78
	3		30	20	11, 25	107	15.02	14.2	63
Cuprous cyanide, talc (20 percent cuprous cyanide)	1		2, 16, 30	20		65	12.45	14.3	64
	2		24	10, 20	11	85	13.05	14.6	63
	3		30	20	11, 25	87	15.31	14.3	64
None (check)								30.8	
Difference required for significance at odds of 19:1								1.7	

These experiments indicate that for the year 1940 a more concentrated control effort using applications at 10-day intervals during the fruit-setting period followed by one application of effective material after the first picking was more effective than a less concentrated 14-day treatment schedule, also during the fruit-setting period but supplemented by an application on the young plants before fruit setting began. Likewise, a trend is indicated in favor of 70 percent cryolite over the 50-percent strength.

Experiments of 1941

Tomato pinworm infestations were very light throughout the 1941 season. No pinworm injury to market or canning tomatoes was reported until late in the season and then only an occasional field was reported to be infested. Experimental plots were located in tomato fields in the Pacoima area of Los Angeles County, which are usually heavily damaged by the tomato pinworm.

The plan of experimental control in 1941 was (1) to test an adhesive diluent in the form of powdered molasses, (2) to test an additional copper compound in the form of copper sulfate, and (3) to give schedule 2 of the experiments of 1940 further trial.

In the Pacoima field C three insecticidal applications were made at 10-day intervals during the fruit-setting period followed by one application after picking began. In Pacoima field D, applications were made during a similar period except that the fourth application was omitted because of rain. Table 10 gives the results of these treatments.

Tomato pinworm injury in both Pacoima fields in 1941 was very light when treatment began and did not build up enough to cause noticeable commercial damage. Copper sulfate was not effective in field C, but was slightly effective if compared with the loss in the untreated plots in field D. Powdered molasses was of no value as an adhesive diluent for cryolite or for cuprous cyanide. Three applications of 50-percent cryolite or of 20-percent cuprous cyanide during the fruit-setting period were less effective than a similar schedule with a fourth application after picking began.

Table 10.—*Injury by the tomato pinworm following the application of different insecticides, Pacoima, Calif., 1941*

PACOIMA FIELD C (PICKING BEGAN SEPT. 27)

Insecticidal material	Dates of application		Quantity of dust per acre (all applications)	Total cost per acre	Fruit injured per plant	Control based on check
	Aug.	Sept.				
			Pounds	*Dollars*	*Percent*	*Percent*
Natural cryolite, talc (50 percent sodium fluoaluminate)	18, 28	9, 30	130	12.09	0.75	86
Natural cryolite, talc, 10 percent powdered molasses (50 percent sodium fluoaluminate)	18, 28	9, 30	151	14.19	.83	85
Monohydrated copper sulfate, lime (20 percent copper sulfate)	18, 28	9, 30	119	6.54	8.26	−15
Cuprous cyanide, talc (20 percent of cuprous cyanide)	18, 28	9, 30	151	19.63	.81	85
Cuprous cyanide, talc, 10 percent powdered molasses (20 percent of cuprous cyanide)	18, 28	9, 30	153	23.97	.44	92
None (check)					5.43	
Difference required for significance at odds of 19:1					1.51	

TABLE 10.—*Injury by the tomato pinworm following the application of different insecticides, Pacoima, Calif., 1941*—Continued

PACOIMA FIELD D (PICKING BEGAN OCT. 11)

Insecticidal material	Dates of application		Quantity of dust per acre (all applications)	Total cost per acre	Fruit injured per plant	Control based on check
	Aug.	Sept.				
			Pounds	*Dollars*	*Percent*	*Percent*
Natural cryolite, talc (58 percent sodium fluoaluminate)	-----	9, 19, 30	80	7.41	0.89	73
Natural cryolite, talc, 10 percent powdered molasses (50 percent sodium fluoaluminate)	-----	9, 19, 30	75	7.05	1.28	61
Monohydrated copper sulfate, lime (20 percent of copper sulfate)	-----	9, 19, 30	61	3.52	1.95	40
Cuprous cyanide, talc (20 percent cuprous cyanide)	-----	9, 19, 30	88	11.43	.61	81
Cuprous cyanide, talc, 10 percent powdered molasses (20 percent of cuprous cyanide)	-----	9, 19, 30	86	11.27	.82	75
None (check)	-----	-----	-----	-----	3.27	-----
Difference required for significance at odds of 19:1	-----	-----	-----	-----	.90	-----

DISCUSSION OF CONTROL STUDIES

Field experiments discussed in the previous section demonstrated that the tomato pinworm may be controlled by the application of cryolite diluted with talc to contain 70 percent of sodium fluoaluminate. As a precautionary measure this dust mixture should be applied once to the plants in the seedbed about a week before the plants are pulled. After the plants are in the field they should be inspected often to determine whether pinworm leaf-folders are present. If the leaves of the young plants are found to be infested, an application of the same material should be made without delay. Whether these earlier treatments have been made or not, the cryolite dust mixture should be applied when the first fruits on the tomato plants are approximately 1 inch in diameter. This application should be followed with three additional applications at intervals of approximately 10 days. These should be timed so that the last application is made after the first market picking or about the time of the first cannery picking. Therefore it may be necessary to delay the last application, depending on the time of the first market picking.

On the basis of 1,000 tomato plants per acre, which is the prevailing planting rate in southern California, the most economical results have been obtained by using a range of from 20 to 25 pounds of cryolite dust mixture per acre for each application, depending on the size of the plants, or a total of approximately 90 pounds for the 4 applications. In any event it is important that the plants be covered thoroughly by the insecticide at each application. Approximately the same quantity per acre should be used in the seedbed. On young plants in the field 10 to 15 pounds per acre are required to cover 1,000 plants with a spread of about 1 foot in diameter.

Although satisfactory control of the tomato pinworm has been obtained by using a cryolite mixture containing 50 percent of sodium fluoaluminate, better results were obtained with a higher strength. If the 50-percent strength is used, the quantity per acre should be increased so that the same number of pounds of the active ingredient, sodium fluoalminate, is applied per acre. On this basis the rate of application on the plants during the fruit-setting period should range from 28 to 35 pounds per acre per application, or a total of 126 pounds for the 4 applications. A corresponding increase should be made in the quantity used per acre on the young plants.

Where the tomato pinworm is a minor pest, or during seasons of light pinworm infestation, control may be effected by a treatment schedule of 4 applications of the 70-percent cryolite mixture at 14-day intervals during the fruit-setting period, provided the fourth application is made after the first market picking.

FIGURE 8.—Tomato plants piled in preparation for burning, as a control measure against the tomato pinworm.

Since certain cultural practices have been shown to be favorable to pinworm development, it naturally follows that some modification of these practices might afford a degree of control. A program of field sanitation should include the destruction of old tomato plants as soon as the marketable crop has been removed, the burial of all cull fruit at marketing time, and the use of uninfested seedlings. Where these practices are not observed, new tomato fields should not be set out near old plant piles or near old fields in which the plants have been left standing. If the plants are to be cut and piled they should be concentrated in small stacks within the field in which they have been grown (fig. 8), or on land that will be plowed later, until they are dry enough to burn. This will allow the pinworm larvae that have matured to pupate in the soil, where they can be destroyed by plowing as soon as the plants have been burned. Tomato growers who prefer to plow the plants under usually cut them up with a disk while they are still green.

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